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Comparative research of orderliness dinamics of road safety systems in the volga federal district and the Russian Federation

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Abstract. This article considers the issues of dynamics of road safety provision systems in three multiscaled systems (Russia, Volga Federal District or VFD and separate subjects of VFD). The indicator of relative information entropy Hn of road safety provision process was taken as the characteristic of system orderliness. The ideology, methodics and results of quantitative assessment of road safety provision systems information entropy H were considered. Time series of modification of relative information entropy Hn of road safety provision systems in 2004…2018 in Russia, Volga Federal District and individual subjects of VFD were presented. Special attention was paid to consideration of the researched process in the Orenburg region and Samara region. This regions is characterized by non-standard, different from general trend dynamics of information entropy H of road safety provision system. The general conclusion of the article is that during last 15 years information entropy of road safety provision systems significantly decreased, i.e. orderliness of formation process of road traffic participants safety greatly increased. However, results achieved in this sphere by VFD regions are still far from best world results.

1. Introduction

Management – transfer of manageable system from current state to desirable (i.e. complex of works on practical implementation of image of the future). During management activities structural and technological orderliness of system and its functioning process increases [1]. In other words, any management activity is intended to fight with entropy – process of growth of uncontrolled chaos in system. Quality of management can be accurately measured by evaluation of system entropy and dynamics of its decline.

State of any transport-technological system is described by enormous set of different characteristics that can be classified by various features (efficiency, quality of functioning, development speed, etc.) [2, 3]. While managing the system, it is necessary to control dozens of traffic parameters and adjust production process in time. It is a complex task. That is the reason of strict regulation of road traffic participants behavior (with the aim of formation of optimal low-entropy system state). It is supposed that such regulation will decrease the degree of chaos in transport-technological system and increase its reliability. For that purpose, system of restrictions imposed on participants of transport process - road traffic rules - has been widely used worldwide for a long time. Increasing of road safety is expressed in development of complex traffic light regulations and initiation of freedom limitation of road traffic participants.

Specifics of transport-technological systems consist in their non-stationarity, continuous variability and not full controllability. In this connection transport management is one of the most difficult types of management activities, entropy in transport systems is quite large. One of the most demonstrative examples of transport systems' entropy is traffic accident rate that is presented only in negative way despite laws of dialectics. According to the estimations of World Health Organization [4] annually in the result of road accidents nearly 1,35 mln. people die, more than 30 mln. people get injured, economic loss because of road accident rate makes $ 550 bln.

2. Formulation of the problem

Management by objectives is used for control of large systems. The distinctive feature of this method is clear understanding of cause-effect relationships, formulation of goals and development of constrained environment for management. Particularly in Russia such approach was formulated in the Target Federal Programme on road safety (for a period of 2013…2020) [5] and moved to the Strategy of road safety [6].

But these documents only declare general directions of road safety development and don't formalize peculiar methods of solving designated problems. There is a variety of instruments that can provide road safety, they can be both engineering and juridical. Efficiency of their usage can be different in various regions of the Russian Federation. It can be explained by national and social-economical specifics of regions. In this connection state of road safety differently forms in each region. And still there is no tool for measurement the degree of road safety system orderliness.

Taken analysis of this issue [1] showed that one of the most efficient instrument of evaluation of the system state from the position of orderliness or forwardness to opposition to negative impact of chaos is assessment of entropy.

This article presents ideology, method of quantitative assessment of information entropy in the road safety provision sphere and results of assessment of dynamics of relative entropy of road safety provision systems in regions of Volga Federal District.

3. Main concepts and definitions

Fundamental concepts of this article are Orderliness and Information entropy. It is necessary to formulate their definitions.

Orderliness – system property, identifying the result of implementation of set of rules and forbiddances that structure system and limit its modifications [7]. Orderliness is an antonym to chaos. Applied to road safety provision processes, orderliness decreases freedom of actions of road traffic participants and at the same time probability of violation or road traffic rules. That automatically leads to decline of probability of road accidents formation and enhancement of final road accidents statistics.

Information entropy – measure of uncertainty (disorganization) of system state [8]. The concept of information entropy, introduced by C.E. Shannon in his paper «A Mathematical Theory of Communication» [9], is a probability of some event. The less the probability of event, the more information it includes [1]. Applied to the assessment of orderliness of road safety provision processes, it means that if information entropy is low, then organizers of transport and technological process can guarantee safe functioning of the system. In the conditions of high uncertainty of system state, we can get set of possible outcomes, including undesirable (road accidents and their consequences).

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4. Method of quantitative assessment of information entropy in road safety provision sphere

The main principles of this method were developed by authors of this article and had already been presented in earlier published works [7, 8, 10]. Moreover, results were showed at scientifically-practical conferences in Saint-Petersburg in 2016 and 2018, in Oryol in 2017…2019, in Moscow in 2018, in Orenburg in 2017, in Tyumen in 2016…2019. Thereby main ideas of this method will be just mentioned in this article.

1. The process of road accident rate formation should be considered from the position of process of quantitative information transmission through the chain «Population – The number of vehicles – The number of road accidents – The number of victims – The number of deaths» (Figure 1). The scale of consideration or road accident formation process can differ: large (World, Continent), medium (Country, individual regions of country), small (city, district of city).

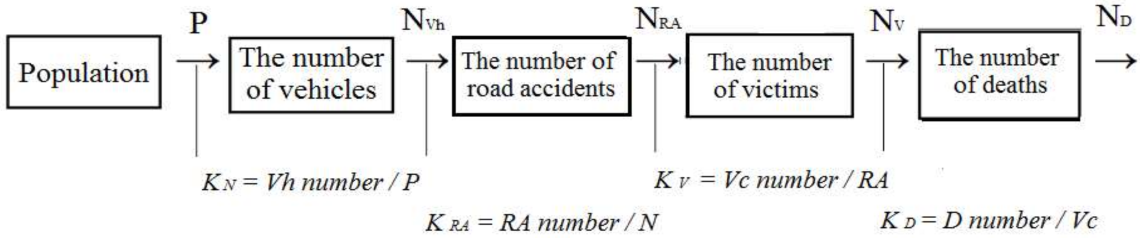

Figure 1. The cause-effect chain of road accident rate formation [10].

2. Calculation of transition coefficients K_i between blocks of the cause-effect chain of road accident rate formation (Figure 1). We will describe this process as 4 sub-processes that have specific coefficients K_N (transformation of number of population into the number of transport vehicles in transport fleet), K_{RA} (transformation of vehicle fleet into the number of road accidents), K_V (transformation of the number of road accidents into the number of road accidents victims), K_D (transformation of the number of road accidents victims into the number of lost in road accidents people).

3. Identifying of the positive of the contribution Q relatively to weights of appropriate elements of examined transformational process within the chain «Population – <…> – The number of deaths in road accident» (1):

$$Q = Q_N + Q_{RA} + Q_V + Q_D = \ln(1/K_N) + \ln(1/K_{RA}) + \ln(K_V) + \ln(1/K_D) \qquad (1)$$

The physical meaning of the positive of the contribution Q of different elements of the chain «Population – <…> – The number of deaths in road accident» into the final result of road accident rate is the measure of information amount or derivative of examined process entropy.

4. Identifying the structure of weight coefficients w_i for assessing the positive of the contribution Q of different elements of the chain «Population – <…> – The number of deaths in road accident». Availability of calculated values w_N , w_{RA} , w_V w_D of positive allows to solve the main problem of entropic analysis – assess the impact of different elements of the chain «Population – <…> – The number of deaths in road accident» on formation of final road accident rate. Above-stated researches were held for each year from period of 2004…2018.

5. Calculation of entropy H in road safety provision systems of Russian Federation and far eastern regions by classic C.E. Shannon's [9] formula (2):

$$H = -\sum_{i=1}^{n} w_i \cdot \ln w_i \qquad (2)$$

where n system elements count (in our case n = 4);

w_i weight coefficients, satisfying the normalization condition, $\sum_{i=1}^{n} w_i = 1$.

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6. Calculation of relative information entropy (3) of the road safety provision systems of the Russian Federation and Volga Federal District regions:

$$H_n = H/H_{\max} = H/\ln(n) \tag{3}$$

Values of *Hn* varies in range from 0 to 1, where 1 means total disorganization or process, while 0 indicates total orderliness and absence of the chaos in system. In reality entirely ordered or disordered systems and processes don't exist. Actual range of *Hn* values is 0.6 (some European countries)…0.9 (some African countries) for the road safety provision sphere.

5. Initial data and results of calculation of relative entropy *Hn* of road safety provision systems in Russia and Volga Federal District

As mentioned above specific methods of assessment of human-technical systems orderliness were previously considered in [7, 8]. This article is presenting only results of estimation of relative entropy *Hn* of road safety provision systems in the Russian Federation, VFD and two regions with opposite rates of entropy change (during 2004…2018).

Tables 1…4 show initial data [11] and results of calculation of relative entropy *Hn* of road safety provision systems in the Russian Federation, Volga Federal District, Orenburg region and Samara region accordingly.

Table 1. Initial data [11] that was used for analysis of road safety orderliness dynamics in the Russian Federation and results of calculation of relative entropy *Hn.*

Year	Population, thousands of people	Vehicles fleet, thousands of units.	The number of road accidents in year, units	The number of victims, people	The number of deaths in road accidents, people	Value of relative entropy *Hn*
2004	144591.0	31439225	207686	284784	34425	0.782
2005	143763.0	33355337	222475	307667	33858	0.783
2006	143041.0	34465080	228309	317011	32640	0.783
2007	142430.0	35446415	233052	324531	33238	0.781
2008	142007.0	38194754	217557	299885	29840	0.769
2009	141904.0	40688499	202967	282305	27603	0.762
2010	141956.0	41648965	199083	276762	26544	0.759
2011	142912.6	43325312	199868	279801	27953	0.755
2012	143030.1	45471096	203597	286609	27991	0.751
2013	143347.1	47881812	204068	285462	27025	0.745
2014	146301.9	52175879	199720	278748	26963	0.734
2015	146307.7	56469971	184000	254311	23114	0.720
2016	146832.3	58025620	173694	241448	20308	0.718
2017	146899.0	59790545	169432	234462	19088	0.713
2018	146828.2	60578772	168099	232907	18214	0.712

Table 2. Initial data [11] that was used for analysis of road safety orderliness dynamics in the Volga Federal District and results of calculation of relative entropy *Hn*.

Year	Population, thousands of people	Vehicles fleet, thousands of units.	The number of road accidents in year, units	The number of victims, people	The number of deaths in road accidents, people	Value of relative entropy *Hn*
2004	31036.0	6839880	39445	53647	6786	0.779
2005	30710.0	6944388	43614	59673	6799	0.779
2006	30511.0	7094131	45928	63362	6465	0.783
2007	30346.0	7360952	45775	63647	6636	0.780
2008	30241.6	7730508	43749	60301	6117	0.772
2009	30157.8	8176113	41041	57139	5751	0.765
2010	30109.0	8176198	40414	56306	5581	0.765
2011	29880.4	8511217	40315	56722	5630	0.762
2012	29808.7	8952948	41710	58740	5755	0.757
2013	29772.3	9373412	44302	62085	5700	0.755
2014	29715.4	10331296	42983	60512	5382	0.743
2015	29715.4	11289174	39101	54271	4476	0.727
2016	29636.6	11496727	38574	53801	4035	0.727
2017	29542.7	11805704	37246	51530	3859	0.721
2018	29397.3	12226022	37585	51943	3646	0.717

Table 3. Initial data [11] that was used for analysis of road safety orderliness dynamics in the Orenburg region and results of calculation of relative entropy *Hn*.

Year	Population, thousands of people	Vehicles fleet, thousands of units.	The number of road accidents in year, units	The number of victims, people	The number of deaths in road accidents, people	Value of relative entropy *Hn*
2004	2163.0	268395	1635	2193	344	0.790
2005	2150.0	514319	3137	4573	503	0.787
2006	2137.9	517806	3587	5116	463	0.792
2007	2126.0	594805	3597	5266	475	0.781
2008	2119.1	600816	3345	5108	460	0.784
2009	2111.5	611236	3110	4474	414	0.769
2010	2113.0	610746	2901	4079	356	0.764
2011	2031.3	649366	2676	3887	366	0.754
2012	2023.8	674703	2449	3589	369	0.745
2013	2016.1	664229	2734	4006	355	0.754
2014	2001.1	793543	2679	3929	419	0.724
2015	2001.1	922857	2362	3351	353	0.691
2016	1989.6	961980	2319	3368	306	0.693
2017	1977.7	996067	2312	3223	295	0.678
2018	1963.0	1000365	2226	3117	273	0.678

Table 4. Initial data [11] that was used for analysis of road safety orderliness dynamics in the Samara region and results of calculation of relative entropy *Hn*.

Year	Population, thousands of people	Vehicles fleet, thousands of units.	The number of road accidents in year, units	The number of victims, people	The number of deaths in road accidents, people	Value of relative entropy *Hn*
2004	3218.1	813833	3642	4817	725	0.742
2005	3201.0	853428	4496	5948	748	0.752
2006	3188.9	884473	5241	7154	752	0.766
2007	3178.0	868799	5189	7259	713	0.773
2008	3172.8	921971	4679	6411	586	0.760
2009	3171.4	967046	4384	6106	584	0.754
2010	3170.0	971609	4267	5997	532	0.756
2011	3215.4	976211	4210	5923	491	0.757
2012	3213.4	1029569	4600	6649	591	0.758
2013	3213.3	1078536	4757	6810	578	0.753
2014	3212.7	1163565	4373	6309	534	0.741
2015	3212.7	1248594	3883	5563	430	0.728
2016	3203.7	1241582	3853	5498	431	0.727
2017	3193.5	1244407	3724	5236	374	0.725
2018	3183.0	1300244	4021	5638	344	0.724

6. Estimation of dynamics of relative entropy *Hn* of road safety provision systems in the Russian Federation and Volga Federal District (VFD)

Figure 2 shows the trend of change of relative entropy for road safety provision systems in Russia and Volga Federal District in 2004…2018.

Value of *Hn* decreases in both cases, therefore the degree of chaos declines in compared road safety provision systems and their orderliness increases. Processes of regulation of road safety provision system functioning in Russia and VFD proceeds in parallel (Figure 2). But in such big system as Russia the proceeding is smoother than in VFD where the process of entropy decline is characterized by greater oscillation amplitude.

Figure 3 shows the trend of change of relative entropy for road safety provision systems in the VFD regions in 2004…2018.

Analysis of Figure 3 allows to understand that, despite regional specifics, practically in all regions level of road safety provision system orderliness increases, because relative entropy *Hn* of road safety formation processes persistently decreases.

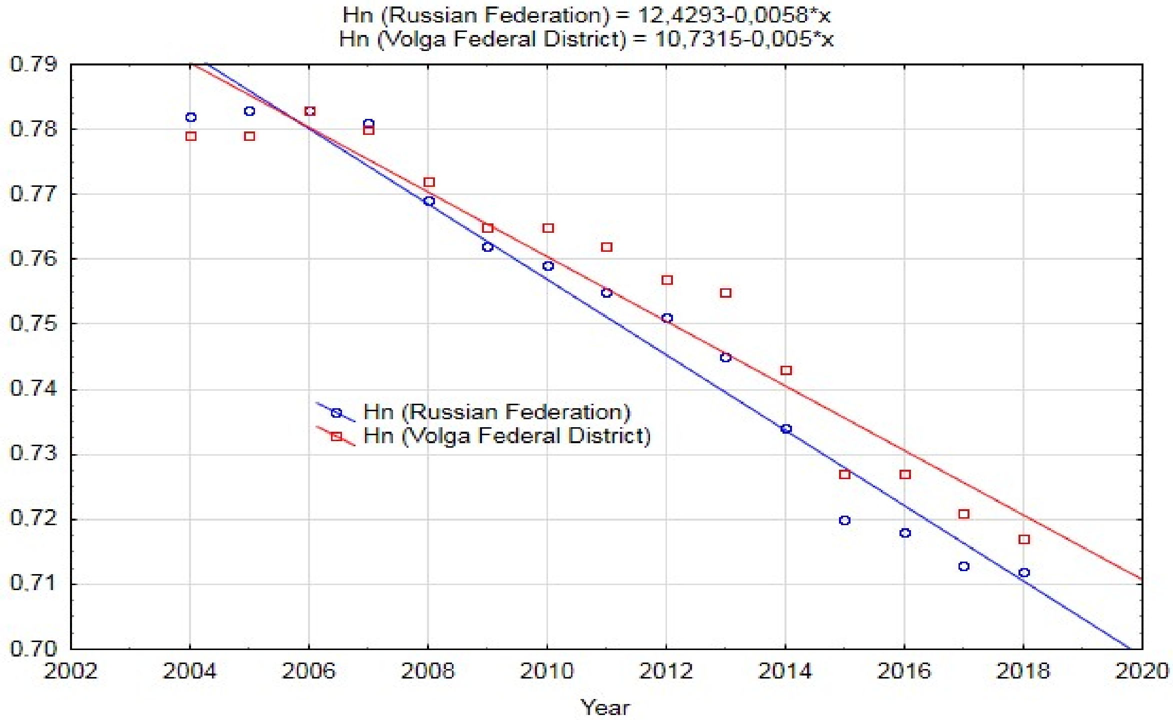

Figure 2. Time series of modification of values of relative entropy *Hn* of road safety provision systems in the Russian Federation and Volga Federal District.

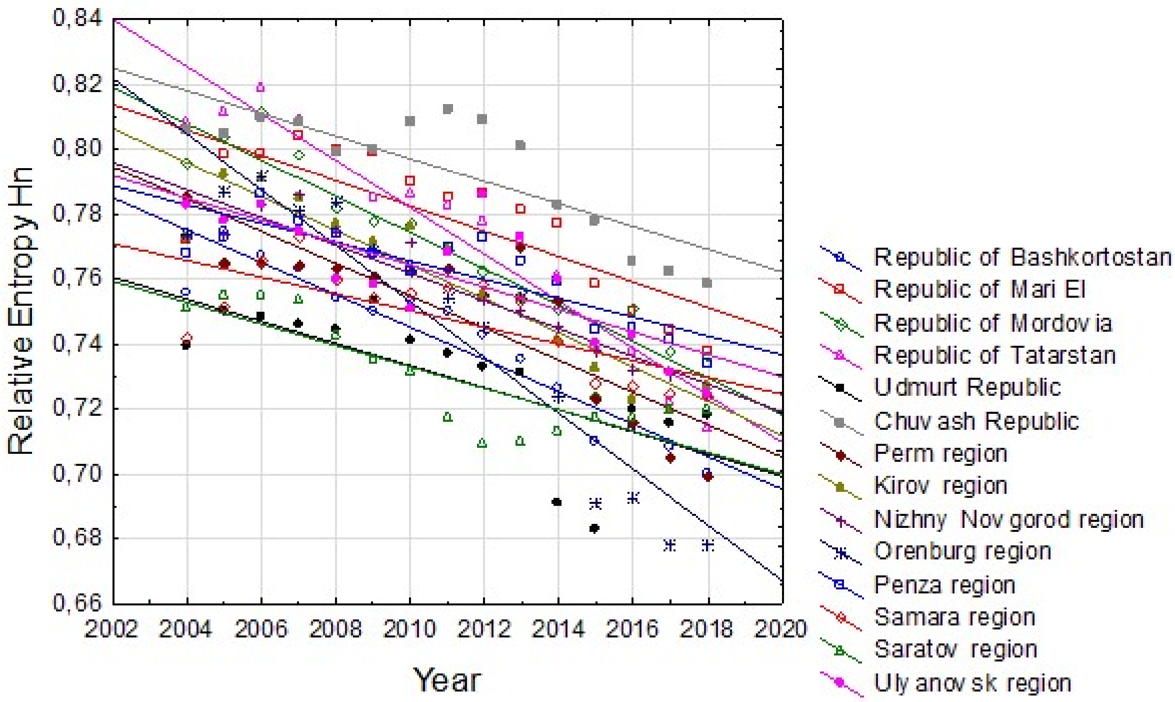

Figure 3. Time series of modification of values of relative entropy Hn of road safety provision systems in the VFD regions.

Table 5 shows the trend of change of relative entropy *Hn* for road safety provision systems in the VFD regions in 2004…2018.

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Table 5. Results of calculation of relative entropy *Hn* in the subjects of the Volga Federal District (2004…2010).

Subjects of the Volga Federal District	Values of relative entropy *Hn* of road safety provision systems in the Volga Federal District subjects						
	2004	2005	2006	2007	2008	2009	2010
Republic of Bashkortostan	0.756	0.775	0.767	0.763	0.754	0.750	0.753
Republic of Mari El	0.772	0.798	0.798	0.804	0.800	0.799	0.790
Republic of Mordovia	0.796	0.804	0.811	0.798	0.782	0.778	0.777
Republic of Tatarstan	0.808	0.811	0.819	0.809	0.799	0.785	0.786
Udmurt Republic	0.739	0.750	0.748	0.746	0.744	0.753	0.741
Chuvash Republic	0.806	0.805	0.810	0.808	0.799	0.800	0.808
Perm region	0.785	0.765	0.765	0.764	0.763	0.761	0.762
Kirov region	0.773	0.793	0.791	0.785	0.777	0.771	0.776
Nizhny Novgorod region	0.773	0.774	0.783	0.786	0.775	0.768	0.771
Orenburg region	0.774	0.787	0.792	0.781	0.784	0.769	0.764
Penza region	0.768	0.773	0.786	0.778	0.774	0.768	0.762
Samara region	0.742	0.752	0.766	0.773	0.760	0.754	0.756
Saratov region	0.751	0.755	0.755	0.753	0.743	0.735	0.731
Ulyanovsk region	0.783	0.778	0.783	0.775	0.760	0.758	0.751

Republic of Bashkortostan	0.750	0.743	0.735	0.726	0.710	0.714	0.708	0.700
Republic of Mari El	0.785	0.786	0.781	0.777	0.758	0.750	0.744	0.738
Republic of Mordovia	0.769	0.762	0.754	0.751	0.724	0.751	0.738	0.736
Republic of Tatarstan	0.783	0.778	0.771	0.761	0.739	0.738	0.722	0.714
Udmurt Republic	0.737	0.733	0.731	0.691	0.683	0.720	0.716	0.718
Chuvash Republic	0.812	0.809	0.801	0.783	0.778	0.766	0.762	0.758
Perm region	0.763	0.755	0.770	0.753	0.723	0.716	0.705	0.699
Kirov region	0.769	0.755	0.754	0.741	0.733	0.723	0.720	0.727
Nizhny Novgorod region	0.762	0.753	0.750	0.745	0.738	0.732	0.730	0.724
Orenburg region	0.754	0.745	0.754	0.724	0.691	0.693	0.678	0.678
Penza region	0.770	0.773	0.766	0.759	0.744	0.745	0.741	0.734
Samara region	0.757	0.758	0.753	0.741	0.728	0.727	0.725	0.724
Saratov region	0.717	0.709	0.710	0.713	0.717	0.717	0.720	0.720
Ulyanovsk region	0.768	0.786	0.773	0.760	0.740	0.743	0.731	0.725

7. Evaluation of dynamics of relative entropy *Hn* of road safety provision systems in the Volga Federal District (VFD) regions

By approximation of time series of modification of value of relative entropy *Hn* of road safety provision systems in the VFD regions during 2004…2018 by linear function *Hn = f(Years)* we got values of parameter *b* of model *Hn = a - b(Years)*. Values of this parameter are presented in table 6.

Table 6. Quantitative values of parameter *b* of model *Hn = a - b(Years)* for regions of the Volga Federal District.

Region of Volga Federal District	Quantitative values of parameter *b* of model *Hn = a - b(Years)*	Coefficient of model determination R^2
Republic of Bashkortostan	-0,0050	0,898
Republic of Mari El	-0,0039	0,645
Republic of Mordovia	-0,0056	0,889
Republic of Tatarstan	-0,0072	0,931
Udmurt Republic	-0,0034	0,530
Chuvash Republic	-0,0035	0,677
Perm region	-0,0050	0,733
Kirov region	-0,0053	0,879
Nizhny Novgorod region	-0,0043	0,894
Orenburg region	-0,0086	0,873
Penza region	-0,0029	0,728
Samara region	-0,0026	0,537
Saratov region	-0,0033	0,716
Ulyanovsk region	-0,0034	0,620

Analysis of quantitative values of parameter *b* of model *Hn = a - b(Years)* specific for different VFD regions allows to make conclusion about specifics of dynamics of growth of orderliness of regional road safety provision systems.

8. Discussion of results

According to the data from table 4 during the last 15 years (2004…2018):

1. The highest pace of growth of road safety provision system orderliness was in Orenburg region (b = -0.0086 or 0.86 % in a year) and Republic of Tatarstan (b = -0.0072 or 0.72 % in a year);
2. Relatively small growth of road safety provision systems orderliness was registered in Samara region (b = -0.0026 or 0.26 % in a year) and Penza region (b = -0.0029 or 0.29 % in a year);
3. In other VFD regions changes of road safety provision systems orderliness equals to the range [-0.0033; -0.0056] or [-0.33 % in a year; -0.56 % in a year];
4. Considering established trends of dynamics of decreasing *Hn* (≈ 0.5 % in a year), nearly 15…22 years required in order to achieve the level of the best world practices of the road safety provision systems orderliness (*Hn* = 0.55…0.60).

9. Conclusion

In the Road safety strategy in the Russian Federation for 2018-2024 [6] the target for Human Risk for 2024 equals to 4 people/100 thousand people or in other words 6000 dead people in road accidents per year in the country with 150 million population. Is it an achievable goal? Taking into account the decline of *Hn* by 0.5 % per year during 2019…2024, it is expectable that *Hn* will decrease by 3 % relatively to $Hn_{\text{RF 2018}} = 0.712$, i.e up to $Hn_{\text{RF 2024}} = 0.691$. This level of dynamics of relative information entropy in road safety provision system of Russia will predict the value of the mortality rate in road accidents as approximately 12.5 thousand people per year. For achievement of ambitious plans, formulated in the Road safety strategy in the Russian Federation up to 2024, *Hn* should have been decreased more significantly than 0.5 % per year. It is hardly possible.

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